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OPTICALLY LINKED EHF ANTENNA ARRAY

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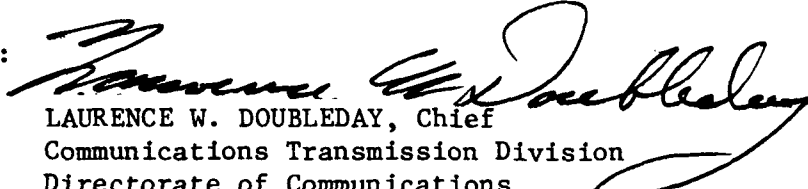
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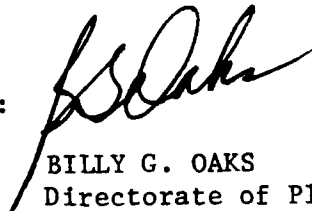
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13. ABSTRACT (Maximum 200 words) <p>This report covers the work done under Task 5 of Project 45194263 entitled, "Communications Adaptive Array Processor Evaluation."</p> <p>Adaptive antenna technology has been an area of interest for many years. The progress to date can be characterized by extensive research on algorithms and processing architectures, development of a large number of prototype systems and fielding of a few systems.</p> <p>Adaptive antenna systems normally consist of two or more antenna elements, two or more receivers, amplitude and phase weighting networks for one or more elements and a signal combiner. For some applications the size, weight, power consumption and cost of multiple receivers, antenna elements and associated radio frequency (RF) cabling can be limiting factors. In spite of these limitations, the impressive interference cancellation capabilities of adaptive antenna systems is highly desirable. Recent</p>				
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advances in photonics technology could provide solutions to the limitations described above. RF modulated lasers, optical cabling and optical detectors could reduce much of the size, weight, power consumption and cost of conventional adaptive array systems.

Using the RADC/DC RF laboratory anechoic chamber and the "Flexible Adaptive Spatial Signal Processor" (FASSP) this effort was performed to establish the feasibility of using optical technology to implement an adaptive antenna array system. This report covers the design, implementation and testing of an optically linked adaptive antenna array. The performance of the optically linked array is evaluated by comparison to a conventional adaptive array.

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1.0 Introduction

This report covers the work done under Task 5 of Project 45194263, entitled, "Communications Adaptive Array Processor Evaluation".

Adaptive antenna technology has been an area of interest for many years. The progress to date can be characterized by extensive research on algorithms and processing architectures, development of a large number of prototype systems and fielding of a few systems.

Adaptive antenna systems normally consist of two or more antenna elements, two or more receivers, amplitude and phase weighting networks for one or more elements and a signal combiner. For some applications the size, weight, power consumption and cost of multiple receivers, antenna elements and associated radio frequency (RF) cabling can be limiting factors. In spite of these limitations, the impressive interference cancellation capabilities of adaptive antenna systems is highly desirable. Recent advances in photonics technology could provide solutions to the limitations described above. RF modulated lasers, optical cabling and optical detectors could reduce much of the size, weight, power consumption and cost of conventional adaptive array systems.

Using the RADC/DC RF laboratory anechoic chamber and the "Flexible Adaptive Spatial Signal Processor" (FASSP) this effort was performed to establish the feasibility of using optical technology to implement an adaptive antenna array system. This report covers the design, implementation and testing of an optically linked adaptive antenna array. The performance of the optically linked array is evaluated by comparison to a conventional adaptive array.

2.0 In-House Test Facilities

RADC/DC has an adaptive array processing test bed. The test bed shown in Figure 1 consists of a rectangular anechoic chamber, a flexible adaptive spatial signal processor (FASSP), a antenna pattern recorder, various types of jammer/desired signal sources and satellite communication simulation and analysis programs.

ADAPTIVE ARRAY PROCESSING TESTBED

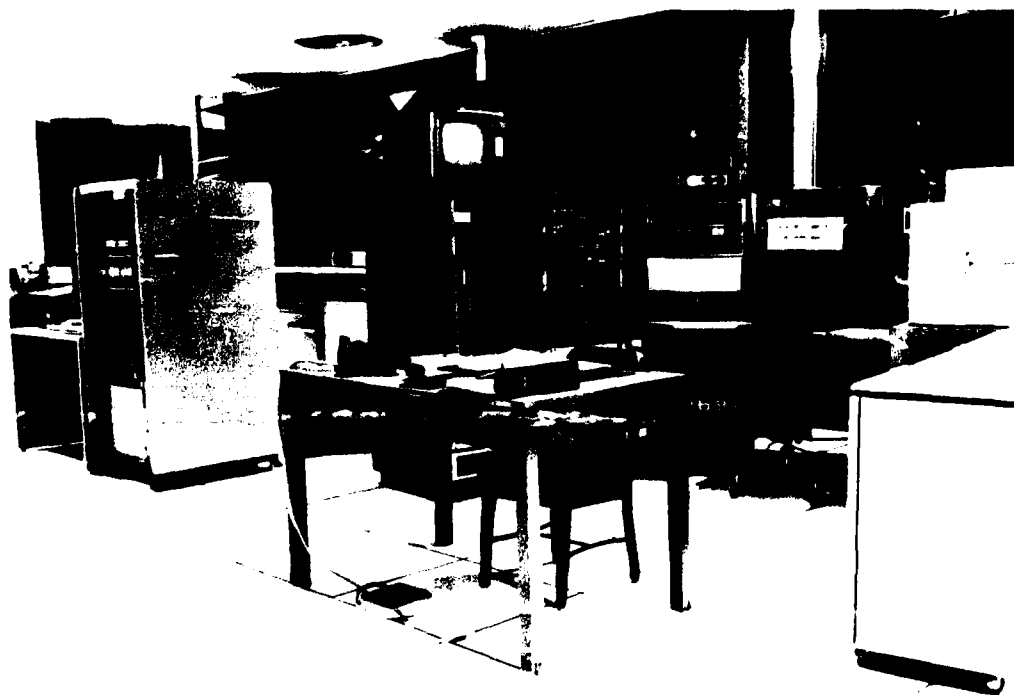


Figure 1

The test bed simulation/analysis computer programs are used to study and compare adaptive processing system concepts, techniques and algorithms. This provides a fast look approach to determine the merit and feasibility of a concept. If the results show promise the concept is further tested using real signals and

adaptive processor hardware to determine the actual benefit attainable. The test bed is reconfigurable and functions as a tool to support the development of methodologies for comparing and evaluating new adaptive array processing algorithms, architectures and techniques suitable for meeting satellite communications requirements (such as those for the Defense Satellite Communications System (DSCS)).

2.1 Anechoic Chamber

The anechoic test chamber shown in Figure 2 is a rectangular structure 40 ft. long, 28 ft. wide and 18 ft. high [5]. The inner chamber is isolated from RF fields from 150 MHz to 18 GHz by at least 100 dB. It has a six foot diameter spherical quiet zone located at its longitudinal axis. The center of the quiet zone is midway between the ceiling and the floor and about 50 inches from the tips of the absorber on the back wall. The receive element array is positioned in the center of the quiet zone to minimize reception of all reflected signals. All chamber walls, ceilings and floors, except walkways, are covered completely with energy (RF) absorbing material. A Scientific Atlanta model 5315C-5 antenna positioner is installed in the chamber. The tip of the model tower (which supports the array elements) is located in the center of the "quiet zone". The chamber is wide enough and has provisions so that several signal sources can be used simultaneously at the front wall opposite to the "quiet zone".

Six feet of the 40 ft. chamber is partitioned off and is used as an equipment room to house the signal sources and antenna positioner controls. Absorber panels are removable to allow access for mounting signal/jammer antennas. Signal and control connections between the chamber and the laboratory equipment (FASSP and Scientific Atlanta 2020 system) are provided through bulkhead feed through panels at each end of the chamber.

ANECHOIC CHAMBER

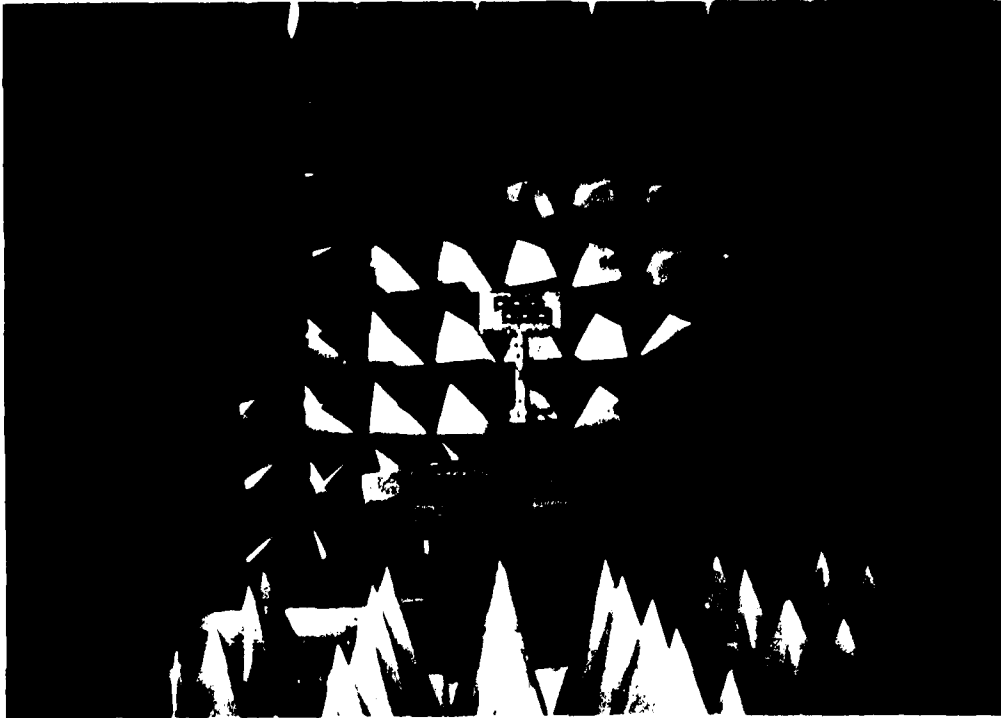


Figure 2

All functions such as source power, frequency, mode and receiver antenna position (pedestal rotation) are controlled from outside of the chamber.

2.2 Flexible Adaptive Spatial Signal Processor (FASSP)

The FASSP [4] test bed is shown in Figure 3. All adaptive Spatial processing systems consist of three generic components:

1. An array of receiving elements (spatial array) to provide the degrees of freedom required to null out a number of directional jamming signals,
2. An adaptive processor that uses the signal samples from

FLEXIBLE ADAPTIVE SPATIAL SIGNAL PROCESSOR (FASSP)



Figure 3

the array receive sensors to compute the adaptive weights that produce the resultant spatial response, and

3. Weighting networks that apply the adaptive weights to the signals from the individual input channels.

The design of adaptive spatial processing systems is very complicated because of the close interaction among these three basic components. Although computer simulations can be used to compare the performance of adaptive algorithms and techniques, the hardware implementation effects cannot always be easily modeled.

With this in mind, RADC/DCCD conceived the ideas of a Flexible Adaptive Spatial Signal Processor (FASSP), which was designed and fabricated for RADC by Syracuse Research Corp. The FASSP is a

general purpose flexible hardware adaptive array processor system that supports the integration/test of adaptive processing algorithms, architectures, techniques and real components.

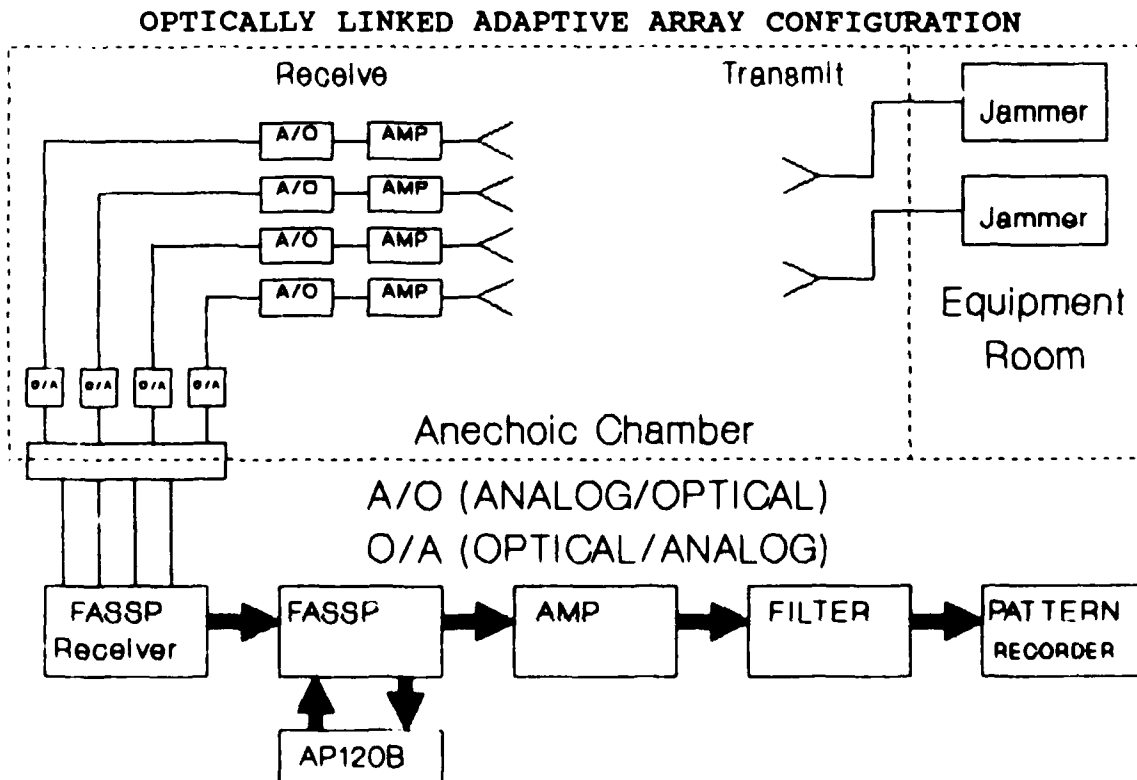
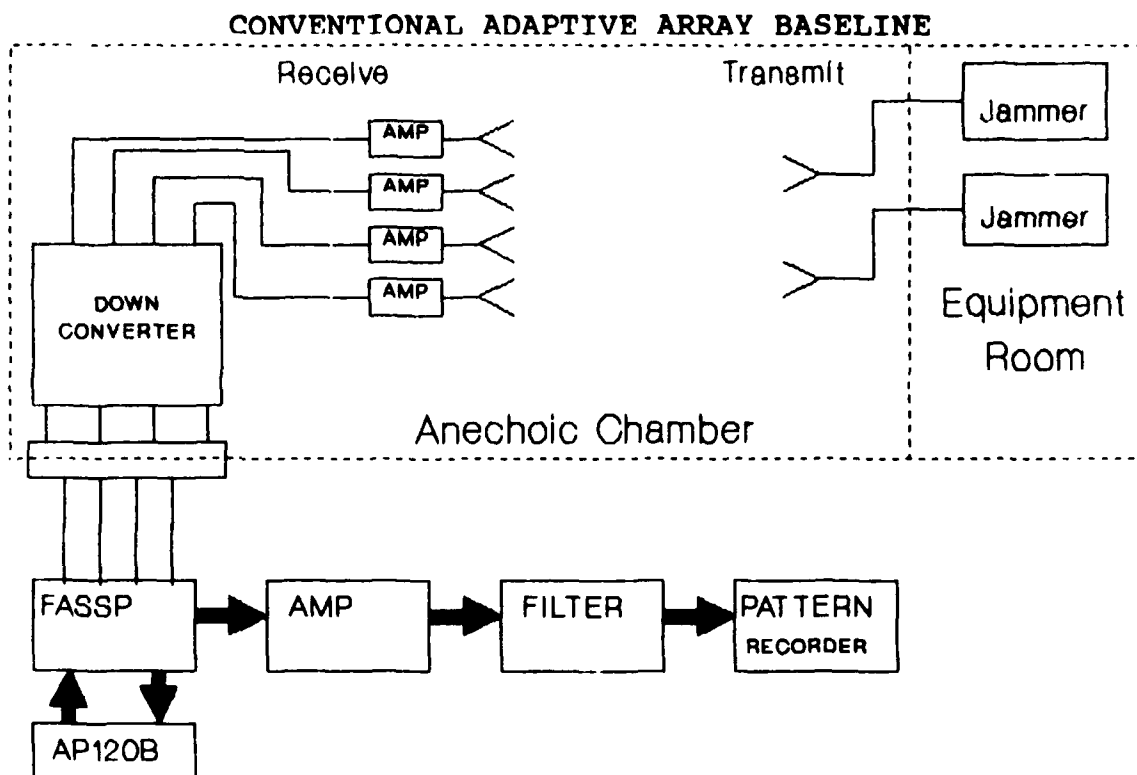
The FASSP system was fabricated with high performance quality components and consists of 12 real RF receivers and weighting networks that are reconfigurable. The designer uses a computer based operating system to select the adaptive algorithms and hardware configuration and specify the necessary system parameters. Adaptive processor performance can then be evaluated against RF signal (desired) and jamming signals using an antenna array and an anechoic chamber.

3.0 Conventional Adaptive Array Baseline

The conventional adaptive array processing system shown in Figure 4 was used as the baseline system configuration. The receiver antenna was a line array of four standard gain horns separated by $3/2$ wavelength spacing. The array was located on the positioner with the elements centered in the chamber quiet zone. The optically linked adaptive array configuration is shown in Figure 5 and is described in Section 4.

The CW and wide band noise jammer antennas were located at the opposite end of the chamber. One jammer transmitter element was positioned broadside/boresight (zero degrees azimuth, zero degrees elevation) to the array and a CW signal was applied. Figure 6 is a plot of the array steered to that CW source.

The array response plot shows that the main beam is centered at zero degrees azimuth and the sidelobes are located at plus or minus fourteen degrees azimuth. The second jammer transmit element was positioned at fourteen degrees centered on one of the side lobes.



Nulling tests were then performed using single jammers at each position.

BEAMFORMED ARRAY PATTERN

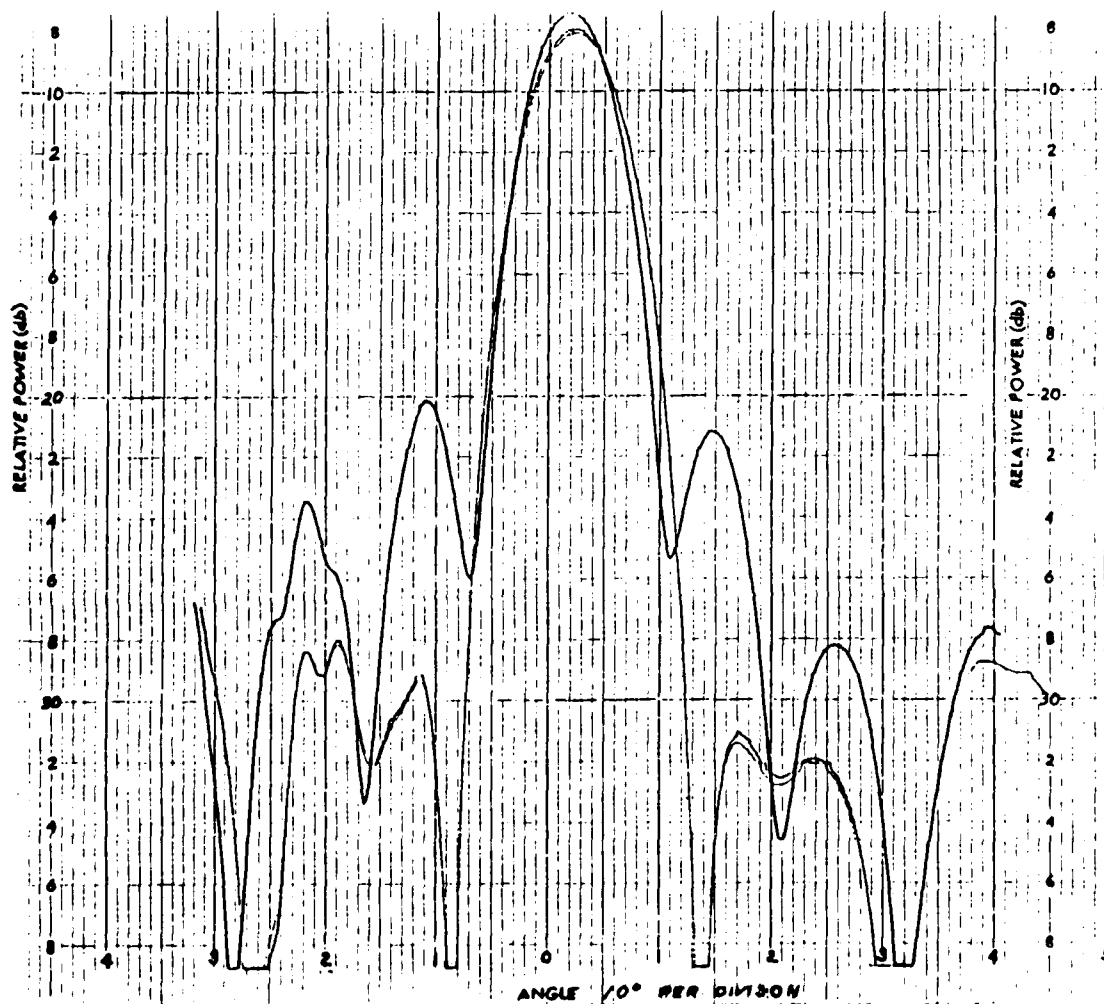


Figure 6

3.1 Baseline Performance Measure

The performance measure used to compare the performance of the optical implementation with that of the standard coaxial implementation was cancellation ratio (CR).

CR's for a given input jamming signal are measured by comparing the adaptive and conventional output power of the adaptive processor. Usually, CR is used to characterize the performance of the adaptive processor against different jamming scenarios. It is a direct measure of the adaptive processor nulling capability and is shown in Equation 1 where P_a is the

$$CR(\text{dbm}) = 10\log(P_a/P_c) \quad 1$$

adaptive processor output power in the adaptive mode and P_c is the adaptive processor output power in the conventional or beamformed mode. Normally adaptive processor output is measured in dbm and thus Equation 2 is used to compute the CR ratio.

$$CR(\text{dbm}) = P_a(\text{dbm}) - P_c(\text{dbm}) \quad 2$$

4.0 The Optically Linked Array

An adaptive array usually consists of a number of antenna elements, a receiver for each element and the RF/IF cabling and connectors necessary to connect the system together. One channel of such a system is shown in Figure 7. The block marked "Flexible Adaptive Spatial Signal Processor" (FASSP) indicates the equipment that performs the adaptive signal processing tasks. Because of the losses in the RF cabling the SHF receivers are co-located with the antenna elements in the anechoic chamber. Along with the RF/IF cabling the receivers introduce another source of unwanted RF/IF radiation. Shown in Figure 8 is an optically linked/connected adaptive antenna array. Because of the very low losses in the optical fiber it is possible to remove the SHF receivers from the chamber and co-locate them with the FASSP. The optical linkage also eliminates the IF cabling from the chamber.

CONVENTIONAL ADAPTIVE ARRAY CONFIGURATION

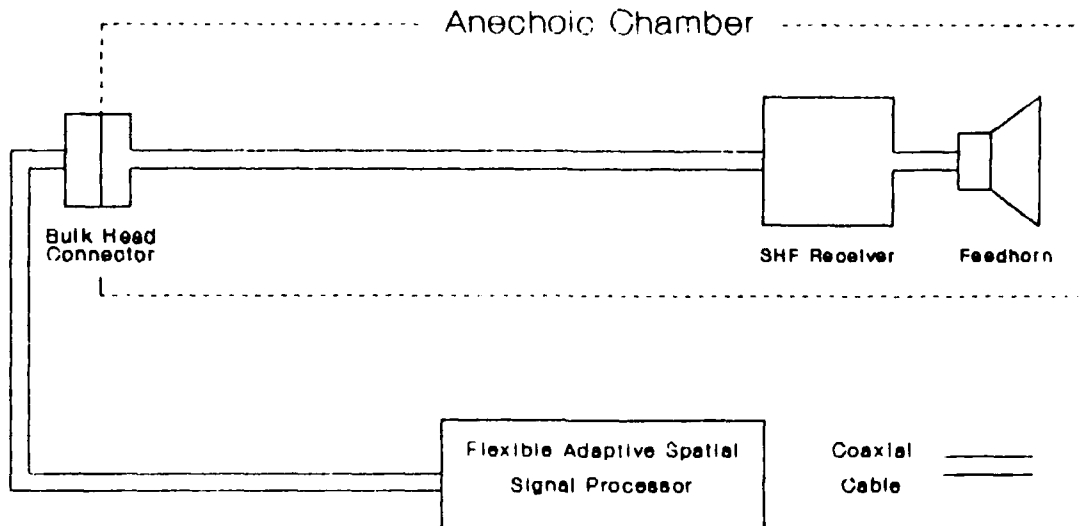


Figure 7

OPTICALLY LINKED ADAPTIVE ARRAY

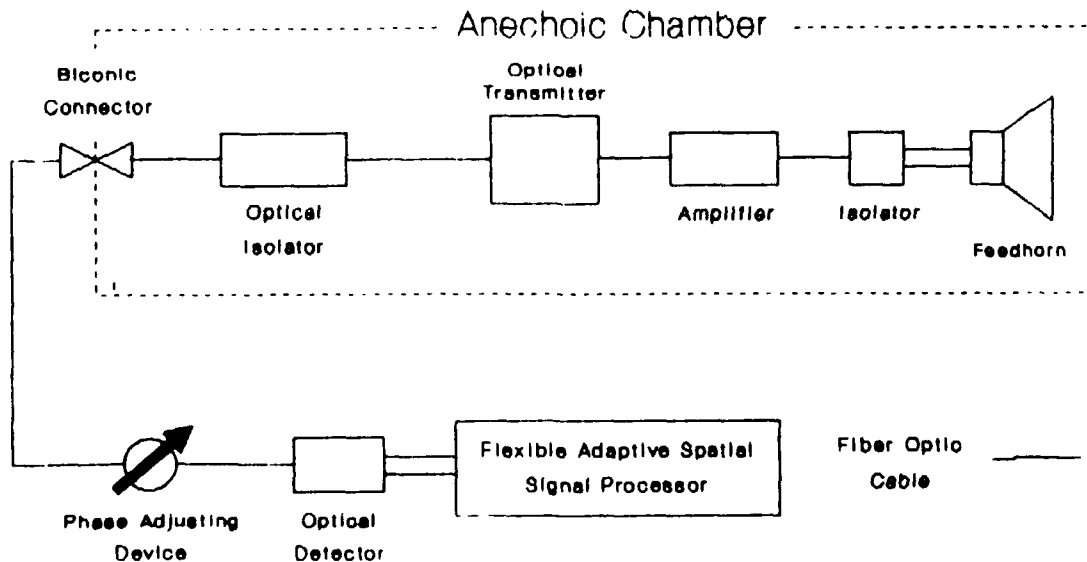


Figure 8

4.1 Hardware Description

Component selection was based on anechoic chamber and associated equipment interface requirements. Since the antenna system was designed to run at 8.41 GHz, the task of optical link selection was significantly simplified. The Ortel TSL-1000 optical transmitter and the Ortel RSL-25 optical receiver were selected based on their frequency range of 10 KHz to 10 GHz.

The maximum received signal likely to be seen at the output of each antenna element (feedhorn) is less than -40dBm. Therefore, 50 dBm gain, narrow band (centered at 8 GHz) Miteq amplifiers were selected to boost the signal. This will supply the Ortel transmitters with power near their maximum RF input level of 12 dBm and thereby allowing us to maximize the usable dynamic range of the links.

Other devices are incorporated in each elemental leg of the antenna system (see Figure 8). These include electrical and optical isolators to prevent impedance mismatch reflections from the feedhorn, and optical reflections to the laser, respectively, 50 meter lengths of fiber and phase adjusting mechanisms to time match the links are also integral parts of the system [1].

4.2 Functional Description

Each array link consists of the equipment described in Section 4.1. An adaptive array is composed of two or more links, usually one for each antenna element in the array. In terms of a single link the RF signal arrives at the array and is received by the antenna element, in this case an SHF feedhorn. The low level signals are amplified to provide an appropriate signal level for the optical transmitters. The optical transmitters put out a single frequency of light the amplitude of which is modulated by

the RF input signal. The light is then transmitted along an optical cable to the phase adjusting device where the electrical length of the optical cable can be adjusted so that all the links in the array can be time and phase matched [1]. The modulated and time and phase matched optical signal then travels along the optical cable to the optical detectors where the light is demodulated and the RF signal is output to the SHF receivers through conventional RF cabling.

5.0 Test and Evaluation

The optically linked array was tested in a manner identical to the conventional/baseline array as described in Section 3.0. Data was collected to plot cancellation ratio for three separate sensors. All of the figures indicated below are identical in form. The horizontal axis (P_e) is the ratio of signal plus noise to noise power as measured at the antenna element. On the vertical axis two quantities are plotted. The quantity (P_c) is referred to as the conventional/unadapted output power as measured at the beamformer/residue output port of the adaptive processor. When measuring this quantity the array is beamformed to broadside and then the interference signal is activated and again the signal plus noise to noise ratio is measured. The quantity (P_a) is referred to as output power after the adaptive processor is allowed to adapt. Again the signal plus noise to noise ratio is measured at the residue output. Using these graphs the CR in dB can be read directly as the difference between the two plotted lines on the graphs.

Shown in Figure 9a is a plot of the conventional and adaptive response. In Figure 9b is a plot of the optically linked conventional and adaptive response. Both Figures 9a and 9b are for a single continuous wave (CW) signal broadside to the array.

Shown in Figure 10a is a plot of the conventional and adaptive response. In Figure 10b is a plot of the optically linked conventional and adaptive response. Both Figures 10a and 10b are for a single CW source in the first sidelobe which is 14 degrees from broadside for the antenna array in use.

Shown in Figure 11a is a plot of the conventional and adaptive response. In Figure 11b a plot of the optically linked conventional and adaptive response. Both Figures 11a and 11b are for a wide band noise (WBN) source broadside to the array.

6.0 Conclusions and Recommendations

Analysis of the data presented in Section 5.0 indicates that the performance of the optical linked array is as good as the baseline conventional array and is in some cases better. During the design and fabrication of the optically linked array it was apparent that optical technology would provide reduced size and weight over the conventionally linked array. The RF cabling associated with a conventional link is bulky and weights about 15 - 20 lbs. as compared to the optical link which is far less bulky and weights only a few pounds, including modulator and demodulator. These size and weight improvements are obtained with no loss in performance, and in some cases with even better performance.

Further improvements are attainable by the following means. An increase in the dynamic range of the optical links could be obtained by using indirect modulation of the lasers verses the direct modulation used for these tests. Single mode fiber optic cable should be used instead of multimode to prevent cable losses due to gradient effects when the fiber is bent or deformed in any way. Using a single laser with external modulators for each antenna element would ensure system coherence and make the system

CONVENTIONAL CW BROADSIDE CR

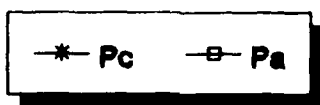
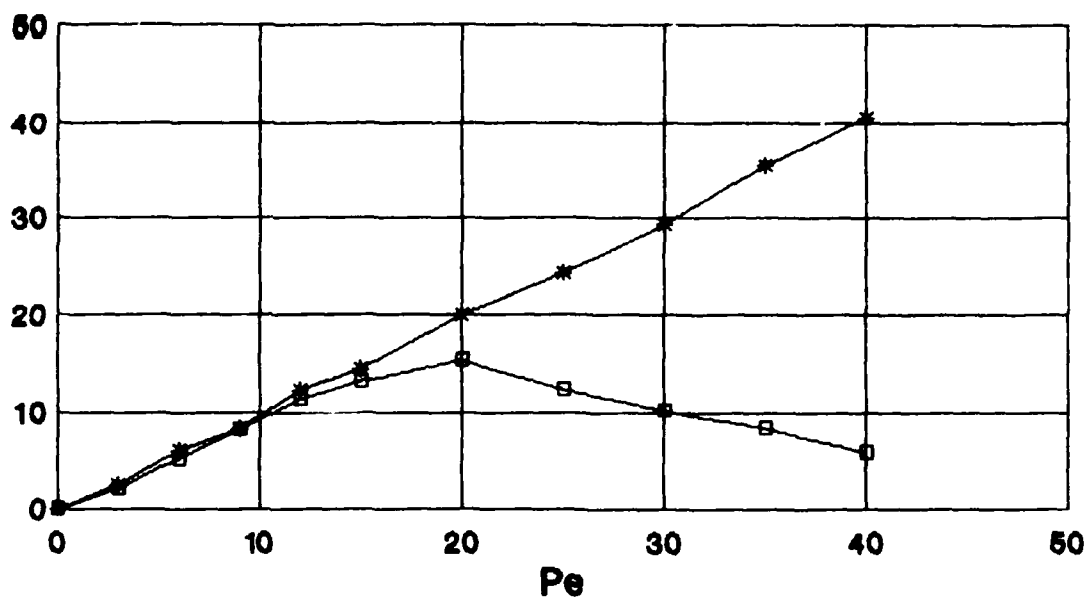


Figure 9a

OPTICAL CW BROADSIDE CR

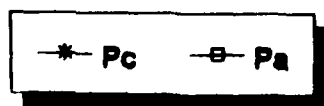
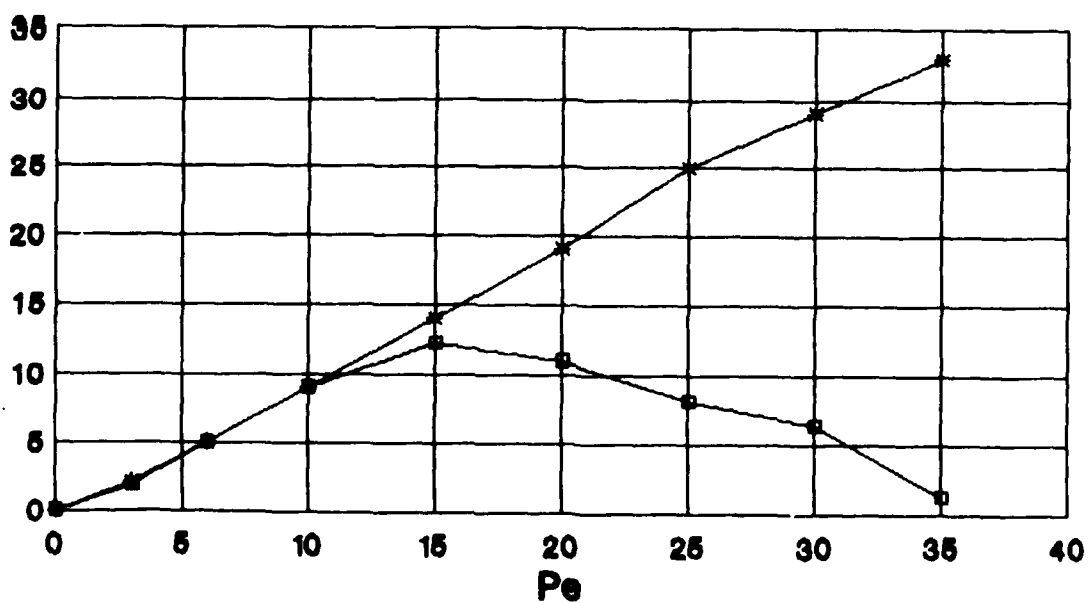


Figure 9b

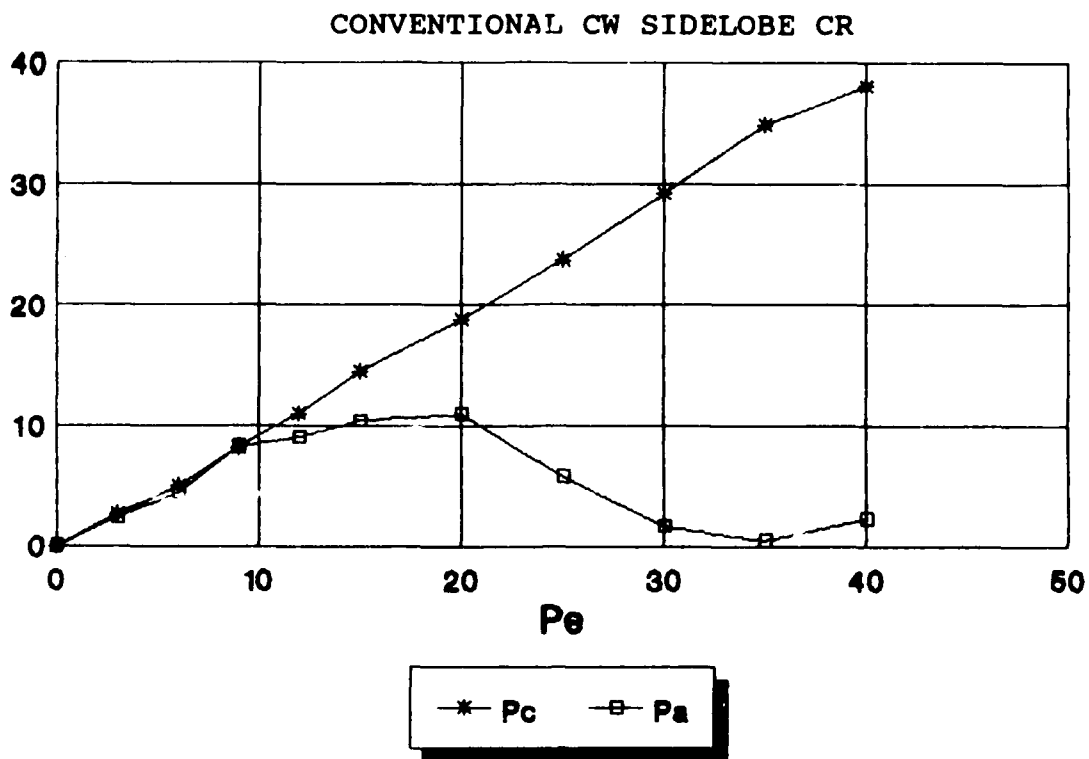


Figure 10a

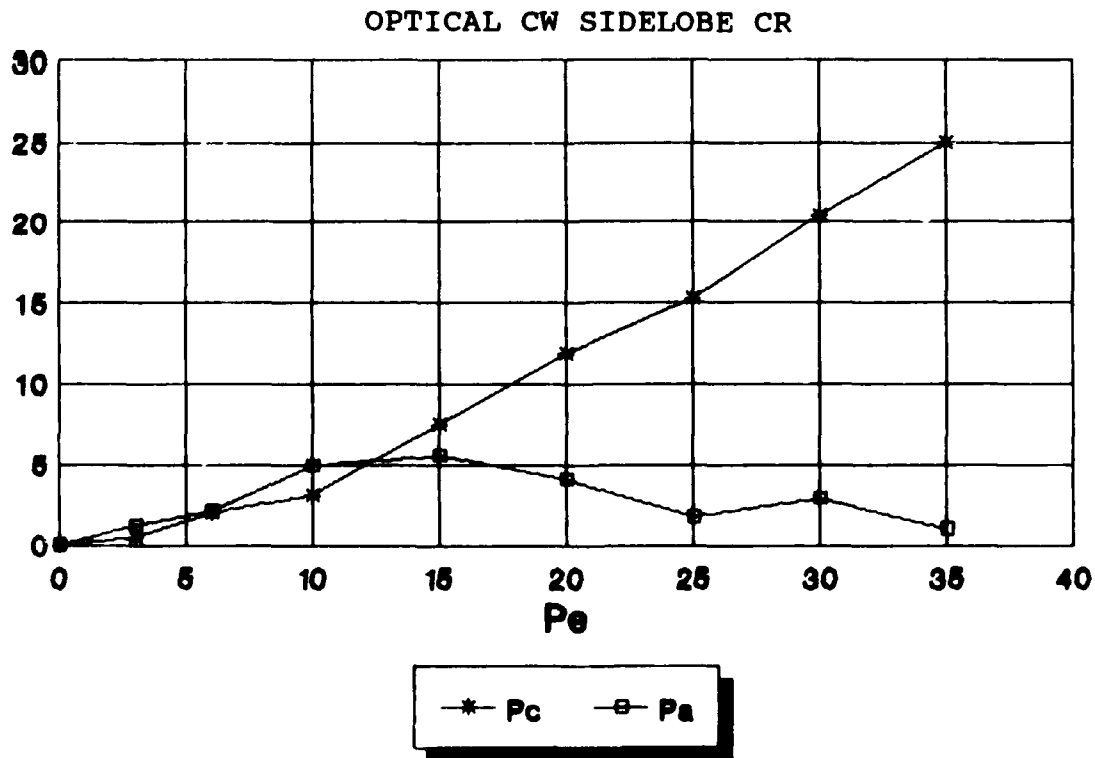


Figure 10b

CONVENTIONAL WBN BROADSIDE CR

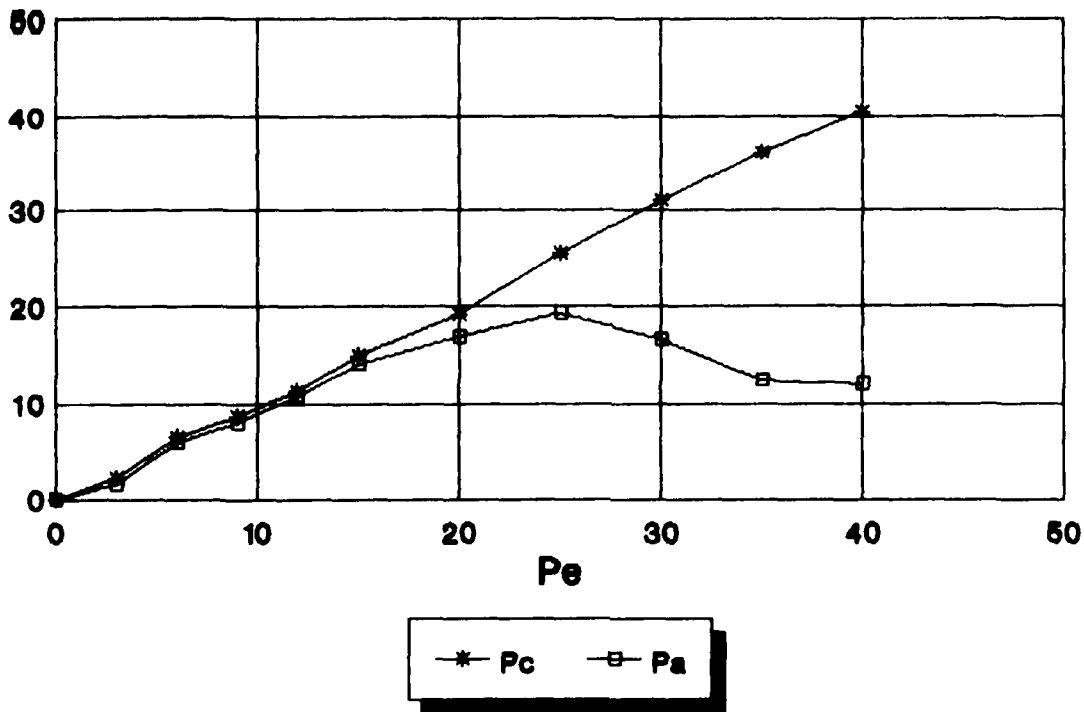


Figure 11a

OPTICAL WBN BROADSIDE CR

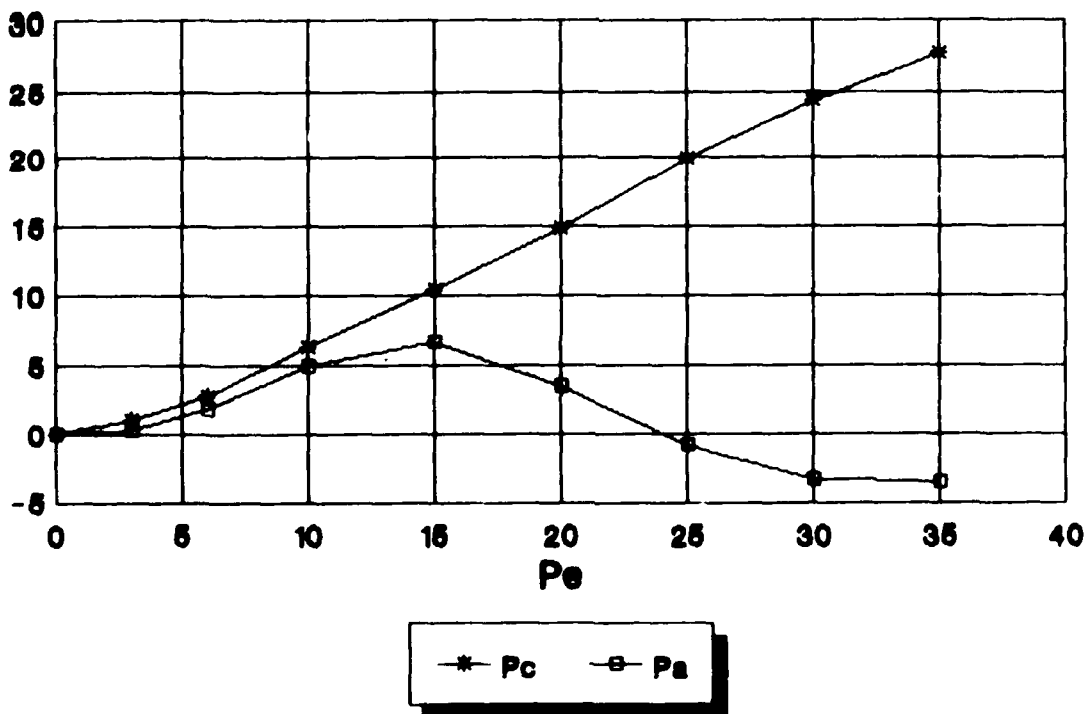


Figure 11b

even more cost effective. The single laser technique would also allow all the elements to be multiplexed on to a single fiber that could then be demultiplexed at the adaptive processor. The detector(s) could be RF biased to provide down conversion thereby eliminating the FASSP receivers. Elimination of the FASSP receivers will result in a reduction in size, weight and power of a complete adaptive antenna system. These means of improvement will be further investigated and verified in future in-house efforts. This RADC/DCCD in-house initial investigation of optical technology, as applied to adaptive antenna systems, indicates that evolving optical technology can and will provide important enhancements especially for mobile platform systems.

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